

CLAIMS

1. A method of arranging at least one workpiece and one or more workpiece processing devices in a manufacturing cell using a programmable computer with a database, each said device either consisting of a rigid body or comprising two or more rigid bodies connected by kinematic joints, one of which bodies is declared to be the base link of said device, and each said workpiece and said rigid bodies having one or more virtual embedded coordinate systems, said method comprising
- entering a geometric description of said manufacturing cell in said database;
- entering a geometric description for each said workpiece and workpiece processing device including kinematic and limit of motion data for each said joint of said devices into said database;
- entering in said database an initial position and orientation of each workpiece and each base link, in which location each is either attached to ground in the cell or to another rigid body;
- entering in said database a tree structure of program steps, the root node of said tree containing a value for each joint of each device in said manufacturing cell at some initial time, and each child node of a particular node in said tree representing an alternative motion in terms of a list of devices which will move should that alternative be chosen, and containing for each joint of each such moving device a value to be attained at the completion of the motion;
- entering in said database identification of attracting pairs of coordinate systems, each member of the pair being one of the embedded coordinate systems of said workpiece of said rigid bodies of said devices at a specified program step;
- entering in said database identification of repelling pairs, each member of which is a workpiece or device in said manufacturing cell;

identifying in said database those workpieces and base links
30 whose locations are to be moved from their initial positions and orientations
and those joints whose values are to be adjusted, such movements and
adjustments being optimized with respect to said attracting pairs and
repelling pairs; and
subjecting prospective locations and joint values to a mathematical
35 optimization analysis to achieve an arrangement of each said workpiece and
devices in said cell in which said attracting pairs of coordinate systems are
coincident, said repelling pairs are separated, and said joint values all lie
within said limits of motion.

2. A method as recited in claim 1 comprising using computer
graphics to display said manufacturing cell, workpieces, processing devices,
attracting pairs and repelling pairs, and to indicate those workpieces, base
links and joints which are subject to optimization.

3. A method as recited in claim 1 wherein said computer
comprises a graphical user interface and said method comprises using said
graphical user interface to add, delete or modify the entering of said
geometric descriptions and positions and orientations of workpieces and
5 devices in the said database, allowing said manufacturing cell arrangement to
be created iteratively and allowing complex arrangements to be developed in
several stages of increasing complexity.

4. A method as recited in claim 1 comprising integrating said
method with computer simulation software so that any sequence of motion
alternatives contained in said tree of program steps can be selected and the
corresponding continuous motion through the sequence can be animated
5 using computer graphics.

5. A method as recited in claim 1 comprising assigning said attracting pairs as consisting of attraction between the origin points of the coordinate systems of said pairs, leaving the relative orientation of the coordinate systems free.

6. A method as recited in claim 1 comprising assigning said attracting pairs as consisting of attraction between the origin points of the coordinate systems and attraction between a secondary pair of points of said systems, said secondary points being a specified non-zero distance along a
5 specified direction of the said coordinate systems, thus causing the line segment from origin to secondary point of the respective bodies to align while leaving rotation about that line segment free.

7. A method as recited in claim 1 comprising assigning said attracting pairs as consisting of attraction between the origin points of the coordinate systems of said attracting pairs and attraction between two or more additional pairs of points of each of said systems, forming congruent
5 geometric entities, so that bringing the corresponding points into coincidence fully constrains the relative orientation of said attracting pairs.

8. A method as recited in claim 1 wherein the function to be optimized is formed as a weighted sum of contributions from each attracting pair, repelling pair, and joint value whereby the attraction of an attracting pair is the sum of the contribution of each designated point pair of the
5 coordinate systems of the attracting pairs and the contribution of a single point pair is a continuous, monotonically increasing function of the Euclidean distance between the points; the contribution of a repelling pair is zero if the bodies are separated by more than a specified upper distance, is infinity if the bodies interfere or are separated by less than a specified
10 minimum distance, and is a continuous, monotonically decreasing function of

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